INTRACRANIAL WAVEGUIDE, RESONANCE CAVITY AND CAVITATION BEHAVIOR

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Background

Advanced Directed Energy (DE) weapon systems threaten new severe biological and medical consequences. Recent events suggest that the intracranial contents are vulnerable to energy exposures with spectral content in the audible and low ultrasonic frequency range, which could include modulated signals on electromagnetic carriers. Previous ONR projects (1960s-~1990) demonstrated inner ear and other intracranial effects of pulsed acoustic and RF energy, but the scientific bases are not well understood.

Quantitative video-oculographic diagnostic technologies have also been useful for documenting early effects of these exposures in clinic and field conditions. For example, vestibular and oculomotor tests show abnormal findings in individuals with recent suspected DE exposures.

Objectives

Objective 1. Develop and validate models for the waveguide, resonance cavity and acoustical cavitation properties of intracranial contents.

Objective 2. Advanced eye movement and pupil monitoring technology for assessing warfighter readiness in operational environments .

Methods

Specifications of commercial ultrasound emitters (40 kHz piezoelectric elements and parametric arrays) were tested from precision audio recordings and with a laser vibrometer. A high frequency power amplifier was used to increase the output of commercially-obtained SoundLazer™ parametric speakers (100 element cards).

Initial computational simulations of sound cavitation and waveguide behavior are implemented in MATLAB (MathWorks) and OpenFoam.

Data from performance of convergence eye movements (binocular disparity steps and sinusoidal pursuit at 0.1 Hz) were analyzed from 52 control subjects, 18 acute mild TBI patients, and 18 individuals who perceived a directed sound exposure in Cuba. Pupil area and eye position were sampled at 100 Hz with an I-PAS video-oculography device (Neuro Kinetics, Pittsburgh PA). Pupillary light responses to 0.42 to 65.4 cd/m^2 homogeneous illumination steps were used to normalize pupil area to percent range Vergence angle was represented in degrees relative to zero at initial fixation. Each eye viewed a white square with red center (0.1° visual angle). For the Step Binocular Disparity task, the subjects viewed disparity shifts in the horizontal plane equivalent to symmetric, approximately ± 1.4° vergence eye movement steps. For the Pursuit Binocular Disparity task, there was sinusoidal convergence (toward nose) and divergence (laterally) movement in the horizontal plane equivalent to symmetric, approximately ± 2.5° vergence pursuit at 10 sec/cycle. Nonlinear least squares regression (MATLAB, MathWorks, Natick, MA) was used to estimate: (1) Parameters for the vergence disparity response as a weighted sum of phasic ($\frac{K_{vh} s e^{-t_v s}}{s+1}$) and tonic ($\frac{K_{vl} e^{-t_v s}}{0.25s+1}$) processes, with delay t_v and gains K_{vh} and K_{vl}, respectively, for converging and diverging half-cycle. Pupil dynamics were fitted from the vergence data by a transfer function for pupil motion, $\frac{K_p e^{-t_p s}}{0.28s+1}$, with delay t_p and gain K_p. The goodness of fit was characterized by R^2.

Results

Parametric speaker presentation of the 40 kHz carrier frequency only is audible to subjects at specific orientations relative to the mastoid process and occiput. With appropriate amplification, it produces cavitation of aqueous solutions across an air gap, which is the subject of the first stage modeling/computer simulation. The device can be used in both physical models of vessels and cadaver studies for resonance within the middle ear.

Ninety percent of the normal subjects, acute mild TBI (mTBI) subjects and putative DE exposure subject groups could classified correctly in discriminant analysis based upon dynamic parameters of binocular disparity eye vergence and concurrent pupil activity. In the binocular disparity step task, the low pass modulation depth parameters K_{vl} converging and diverging) and vergence R^2 distinguished the mTBI subjects from control and DE exposed subjects, while the pupil constriction gain (re: vergence) and associated R^2 distinguished the DE exposure. The pursuit test parameters further supported these distinctions. Therefore, this test has the potential for application in far-forward, differential detection of mild traumatic exposures to blunt trauma or other DE sources.

Fig. 1. Left panel. COTS parametric speaker array of 100 piezoelectric elements emitting a 40 kHz carrier signal (SoundLazer™). **Middle panel.** Cavitation of tap water across an air gap by the carrier frequency of the parametric speaker (with appropriate amplification). **Right panel**. Base model of COTS I-PAS™ VOG system with Virtual Reality display (Neuro Kinetics, Inc Pittsburgh, PA).